Continental Shelf Research ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Continental Shelf Research

journal homepage: www.elsevier.com/locate/csr

Trapping and episodic flushing of suspended sediment from a tidal river

Mark Pritchard [a,*], Malcolm Green [a,b]

[a] National Institute for Water and Atmospheric Research, PO Box 11115, Hamilton 3216, New Zealand
[b] Streamlined Environmental Ltd., 510 Grey Street, Hamilton East, Hamilton, New Zealand

ARTICLE INFO

Article history:
Received 22 February 2016
Received in revised form
5 July 2016
Accepted 12 July 2016

Keywords:
New Zealand
Kaipara Harbour
Wairoa tidal river
Estuary
Tidal asymmetry
Tidal pumping
Gravity circulation
Sediment flux

ABSTRACT

Recent studies suggest that tidal forcing can be as important as gravitational circulation in maintaining an estuarine turbidity maximum (ETM). It is further postulated that a long-term mass balance between the import and export of sediment in an estuary may require episodic large river discharges or 'freshets' to flush sediment out of the ETM towards the open sea. In this study, we use a 2-month data set from a mooring in a tidal river that drains into a large drowned-river-valley estuary (Kaipara Harbour, New Zealand) to investigate interactions between tidal-current asymmetry and gravitational circulation. During baseflow river discharge and on spring tides, suspended-sediment transport was directed up-channel (landwards), driven by tidal pumping due to tidal-current asymmetry. During neap tides, the suspended-sediment flux was approximately zero. The data suggest that the bed was not locally erodible and that bed sediments at the site were being supplied by an ETM. The ETM only migrated far enough down channel to be observed at the mooring site during spring tides when the tidal excursion was longer. Suspended sediments were effectively trapped and recycled within the ETM. During and after two freshets, high river discharge displaced saline water from the tidal river, water-column stratification strengthened and the surface and bed current speeds increased. As a result, the advective component of the down-channel directed suspended-sediment flux increased. This provided a transport pathway for sediment out of the otherwise tidally pumped, flood-dominant system. We conclude that largest export of sediments out of the tidal river would potentially occur when a large freshet coincides with an apogean spring tide.

1. Introduction

The long-term morphological evolution of estuaries depends on the amount of fluvial sediment imported by rivers versus the amount of sediment that is exported from the system to the sea. In many stratified or partially stratified estuaries the sediment balance arises from the net effect of estuarine gravitational circulation, the tide and sediment particle dynamics.

Differences in density between seawater and freshwater inflows over many days and weeks can establish a gravitational circulation in the estuary. This typically manifests as a near-surface barotropic flow towards the sea and a baroclinic upstream flow at the bed (e.g., Officer, 1976). The upstream limit of saltwater intrusion in stratified and partially stratified estuaries is marked by an estuarine turbidity maximum (ETM). The ETM is a region of elevated turbulence and high suspended-sediment concentration (SSC) that forms in response to current flows and particle settling, deposition, erosion and resuspension (Dyer, 1997; Mitchell et al., 2012).

Tidal currents can break down stratification through vertical mixing and tidal straining, thus decreasing the strength of the gravitational circulation (Simpson et al., 1990). Tidal currents also modulate the tidal excursion over the spring–neap cycle, which changes the position of the salt-wedge intrusion and the ETM. Tidal currents can be non-linearly modified by the basin morphology of the estuary (Friedrichs and Aubrey, 1988), resulting in distortion of the tide by higher harmonics or overtides (Dronkers, 1986).

Asymmetry in tidal currents is caused primarily by the superposition on the principal M_2 semidiurnal astronomical tide of M_4 and higher harmonic overtides, which can result in tidal-current ebb or flood dominance (LeBlond, 1978; Parker, 1991; Speer et al., 1991; Song et al., 2011). As sediment transport is approximately proportional to the cube of the current speed, tidal-current asymmetry can result in a net sediment transport (Uncles et al.,

* Corresponding author.
E-mail address: m.pritchard@niwa.co.nz (M. Pritchard).

http://dx.doi.org/10.1016/j.csr.2016.07.007
0278-4343/

Please cite this article as: Pritchard, M., Green, M., Trapping and episodic flushing of suspended sediment from a tidal river. Continental Shelf Research (2016), http://dx.doi.org/10.1016/j.csr.2016.07.007

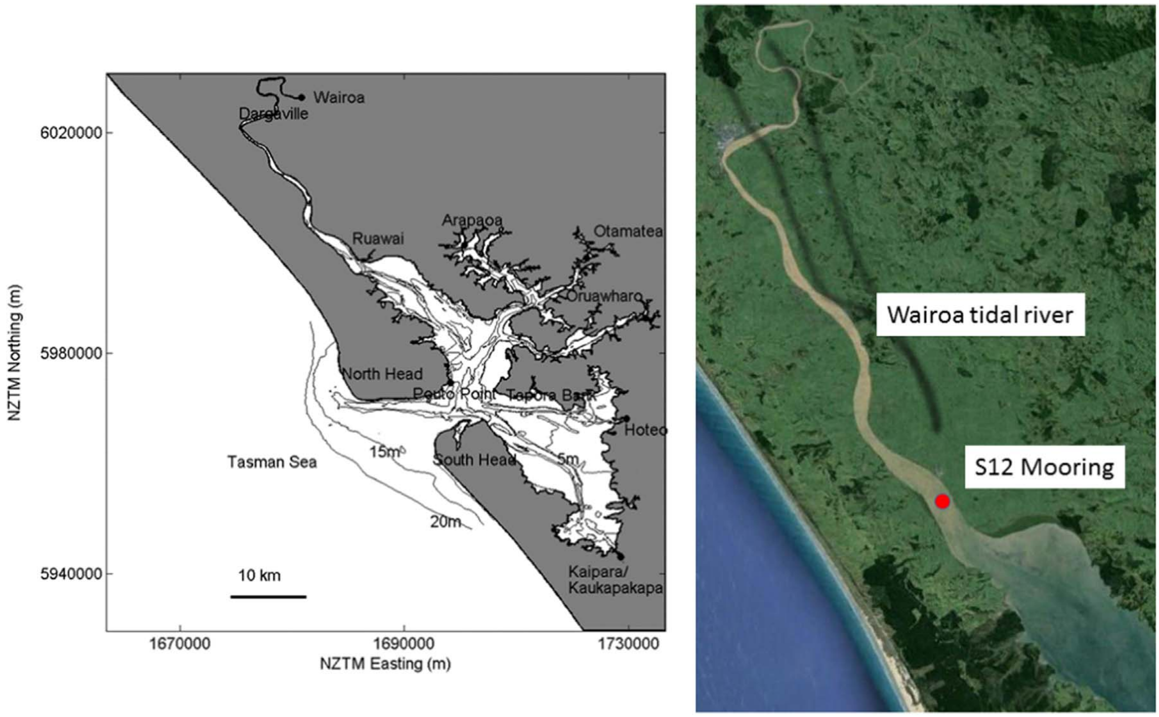

Fig. 1. Regional (NZTM) and site specific map showing the location of the Site 12 mooring site in the Wairoa tidal river estuary in context of the larger Kaipara Harbour. Image is courtesy of Google Earth®.

1985; Uncles and Stephens, 1993; Dyer, 1997).

Recent studies suggest that tidal forcing can be as important as gravitational circulation in maintaining the ETM in some stratified estuaries (Sommerfield and Wong, 2011). Assuming that sediment is largely trapped in the region of the ETM, a long-term mass balance between the import and export of sediment may require episodic large river discharges or 'freshets' that break down and push the salt wedge towards sea (Geyer et al., 2001; Ralston et al., 2013).

In this study, we use field measurements over a 2-month period from a tidal river that drains into a large drowned-river-valley estuary (Kaipara Harbour, New Zealand) to investigate the way sediment transport arises from interactions between tidal-current asymmetry and gravitational circulation. The effects of two freshets on the gravitational circulation and an associated turbidity maximum are examined.

2. Regional setting

Kaipara Harbour is the largest natural estuary in the southern hemisphere (Heath, 1975). It is formed from a system of drowned river valleys that interconnect at a central confluence that opens out through a single inlet to the Tasman Sea (Fig. 1). The main freshwater discharge to the northern part of the harbour is through the Wairoa River, which drains 63% of the total catchment area.

The tide range at Pouto Point is 1.9 m on neaps and 2.8 m on springs (Nichol et al., 2009). Water levels in the arm of the harbour that extends up into the Wairoa River (which we term here the "Wairoa tidal river") become increasingly asymmetric and attenuated moving landwards (Hume and Male, 1985).

Water depth in the main channel of the Wairoa tidal river varies between 2 and 6 m. The cross-section is approximately parabolic but with marginal intertidal flats and mid-channel shoals that become exposed at low tide (Hume and Male, 1985; LINZ NZ4625 Nautical Chart).

Wairoa River freshwater discharge measured between 1974 and 1976 ranged from 13.5 $m^3 s^{-1}$ in summer to 240 $m^3 s^{-1}$ in winter (Hume and Male, 1985). The Water Resource Explorer NZ (WRENZ) database operated by NIWA reports the mean annual freshwater discharge for the Wairoa River as 88 $m^3 s^{-1}$ and the mean annual flood as 3700 $m^3 s^{-1}$ at Ruawai (see Fig. 1) (Gibbs et al., 2012). Recent catchment modelling work by NIWA using the catchment-based TopNet modelling platform suggests that the Wairoa River is flashy and flows can increase by several orders of magnitude in response to rainfall that accompanies weather systems that pass through the region (Pritchard et al., 2013). Typically, the flood hydrograph rises rapidly over several hours and then falls to the background level over several days after the weather system has passed through the region (Pritchard et al., 2013).

3. Mooring data

Fig. 1 shows the position of an instrumented mooring (Site 12) that was deployed two times at the same location in the Wairoa tidal river from March to May 2011. The mooring was equipped with a 1200 kHz RDI Workhorse acoustic Doppler current profiler (ADCP) and 2 DOBIE-OCT wave recorders. Table 1 gives deployment and sampling details for both mooring deployments.

The ADCP was mounted on the seabed looking upwards. We extracted near-surface velocity from the record by tracking the velocity data in the bin 0.5 m below the sea surface as recorded by the ADCP pressure transducer. Pritchard et al. (2012) showed that depth-mean currents at Site 12 were strongly rectilinear with current directions oriented along the longitudinal axis of the channel. Principal component analysis of the ADCP data showed that surface and bed currents are also rectilinear. We denote the along-channel current as U and designate flood flows as negative and ebb flows as positive.

Each DOBIE-OCT wave recorder was fitted with a pressure sensor, an optical backscatter sensor (OBS) and a conductivity–

Please cite this article as: Pritchard, M., Green, M., Trapping and episodic flushing of suspended sediment from a tidal river. Continental Shelf Research (2016), http://dx.doi.org/10.1016/j.csr.2016.07.007